G(B)13019 - GEOTECHNICAL INVESTIGATION REPORT
Sewage Treatment Plant at Doddabele, Bengaluru

DRAFT REPORT

1. INTRODUCTION

2. M/s ** propose to upgrade/augment the capacity of the existing ** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru.

3. To design the substructures for the proposed additional structures for the Sewage Treatment Plant, adequate information regarding the substrata conditions is required. For this purpose, detailed geotechnical investigations had been undertaken.

4. This report contains the details of the geotechnical investigations conducted along with the results and analysis of the investigations and recommendations.

5. Geotechnical investigations for this purpose had been carried out as per the authorization of Work Order No: , issued by M/s ****.

1. PROJECT DETAILS

2. Site Location

The site is located within the existing premises of BWSSB *** Sewage Treatment Plant at Doddabele, Bengaluru.

2.2 Site Layout and Topography

2.2.1 A Key plan showing the overall layout of the Sewage Treatment Plant is given in fig.1a.

2.2.2 Schematic site plans showing the dimensions and other details of the sites for the proposed Disc Filter unit and the proposed Blower Building unit are given in figs.1b & 1c respectively.

2.2.3 The general level within the above sites had been observed to be same as the internal road levels.

2.2.4 Vegetation in the form of grass and trees had been observed within the sites during the period of field investigations.

2.2.5 Existing chlorination building is located on the Eastern side of the proposed disc filter unit while the existing gravity sludge thickener unit is located on the Western side of the proposed disc filter unit in close proximity.

2.2.6 Existing grit basin unit is located on the Eastern side of the proposed blower building unit while the existing Parshall fume unit is located on the Southern side of the proposed blower building unit in close proximity.

2.2.7 Vrishabhavathi nalla/river is passing along the Eastern and Southern boundaries of the existing Sewage Treatment Plant in very close proximity.

2.2.8 The colour of the surface earth had been observed to be Brown to Brownish yellow.

2.3 The Structure

2.3.1 The proposed structures of the Sewage Treatment Plant consist of :

a) **Disc Filter Unit** - Disc Filter Tank, Outlet Drop Chamber and Pumping Station. The dimensions of the Disc Filter Tank is 7.3m x 4.1m with a bottom level of 3.78m as per the Section drawing provided by the client.

b) **Blower Building**

2.4 Seismic Zone

The present site is located in the Seismic Zone II, as per the seismic zoning map of India given in BIS code IS : 1893, Part 1 - 2016.

3.0 OBJECT OF INVESTIGATIONS

3.1 For designing the foundation system of the proposed Structures, the following data are required :

a) Type of foundation

b) Depth below the ground level at which the foundation system is to be laid.

c) Allowable bearing pressure at the foundation level.

3.2 To determine the above factors, the following information would be required:

a) The subsoil/rock profile indicating thicknesses of the various soil/rock strata, to a depth within the influence zone below the foundations

b) Engineering properties of the soil/rock strata at various levels

c) Physical characteristics of the soil/rock strata

d) Variation of strength of soil/rock strata with depth.

3.3 For evaluating the above parameters, field investigations and laboratory investigations on the soil/rock samples collected during the field investigations, have been carried out.

3.4 The results from these investigations have been analysed to provide the recommendations for the design of foundations.

4.0 SCOPE OF INVESTIGATIONS

4.1 The scope of investigations as stipulated by the client consists of :

a) Conducting progressing boreholes in soil strata down to 15m depth below existing ground level or minimum 5m drilling in rock strata at four (4) locations

b) Conducting Earth Resistivity Test at one location.

c) Conducting Field Permeability Test at one location.

d) Conducting Percolation Test at one location.

e) Excavating Trial Pit down to a maximum depth of 1.5m below the existing ground level at one location.

f) Conducting relevant laboratory tests on soil/rock samples recovered.

g) Preparation and submission of a detailed report containing the details of the tests carried out, their analysis and recommendations regarding the foundation system to be adopted.

4.2 The following operations were to be undertaken while progressing the boreholes:

a) Conducting standard penetration tests at regular intervals in soil strata.

b) Recovering undisturbed soil samples from various levels of the subsoil strata.

c) Recovering rock core samples in rock strata.

d) Recording ground water table levels, if met with.

5.0 FIELD INVESTIGATIONS

5.1 Preliminary Details

5.1.1 Field investigations had been carried out in the months of December 2024 & January 2025. The weather is cloudy with occasional clear skies at the time of investigations

5.1.2 A schematic site plan showing the test locations has been given in fig.1.

5.2 Boreholes

5.2.1 Four (4) boreholes designated as BH1 to BH4 were progressed from the existing ground level by using rotary drilling machine to study the substrata conditions at the site.

5.2.2 Filled up strata in the form of loose soil had been encountered in the boreholes BH1, BH3 & BH4 and extending down to depths varying between 0.7m and 1m below existing

5.2.3 Refusal/rock strata had been encountered at varying depths in all the boreholes.

5.2.4 Drilling in refusal/rock strata had been carried out in all the boreholes to ensure that adequate information regarding the rock strata below the likely foundation level is obtained.

5.2.5 Drilling in refusal/rock strata had been carried out down to a maximum depth of 5m in the refusal/rock strata, by rotary drilling machine using double tube core barrel fitted with diamond bits of Nx size.

5.2.6 The depths at which refusal strata/rock strata had been encountered and termination depths of the boreholes are given below:

Borehole No.	**Depth(m) of Refusal/ Rock Strata Below E.G.L.**	**Termination Depth(m) Below E.G.L.**
BH1	4.6	9.6
BH2	4	9
BH3	2.8	7.8
BH4	2.9	7.9

E.G.L. : Existing Ground Level

5.2.7 In the soil strata, Standard Penetration Tests (SPT) had been conducted at regular intervals. Disturbed soil samples recovered from split spoon samplers had been retained for identification purposes.

5.2.8 Standard Penetration Tests had also been conducted in weathered rock strata for the confirmation of refusal/rock strata.

5.2.9 Undisturbed soil samples had been recovered by thin walled tube samplers conforming to IS:2132.

5.2.10 Disturbed soil samples had been enclosed in polythene bags.

5.2.11 Soil/rock samples had been transported to the laboratory for testing purposes.

5.3 Ground Water Table

The ground water table was encountered at an average depth of about 4.2m below existing ground level in the boreholes at the time of investigations carried out in the months of December 2024 and January 2025. The ground water table can be expected to be rise further during the rainy season.

5.4 Trial Pit

One (1) no. of Trial Pit was excavated at the specified location. The trial pit has been designated as TP1. Trial Pit of size 1.5m x 1.5m in plan, was excavated down to about 1.5m depth below existing ground level as per scope of work. Disturbed and Undisturbed soil samples were collected from the trial pit for conducting relevant laboratory tests.

5.5 Earth Resistivity Test

5.5.1 One Earth Resistivity Test has been carried out at the specified location. The Earth Resistivity Test has been designated as ERT1. This test has been conducted using Wenner's four pole electrode method as per IS:3043.

5.5.2 In this test, four electrodes had been driven into the ground surface along a straight line at equal intervals. The tests involves the passing of a current through the outer two electrodes called the current electrodes and the measurement of the voltage difference between the two inner electrodes called the potential electrodes. The ratio of the voltage difference measured to the current passed gives the resistance. An electrical megger had been used to determine the resistance directly at the site. The resistance had been so determined for various electrode spacings.

5.5.3 The above procedure had been repeated for eight different directions at selected location, as per the standard procedure.

5.5.4 As existing buildings/structures and roads are located in all directions, the test had been carried out only up to an electrode spacing of about 5m in North, North-East, South-East, South, West and North-West directions and up to an electrode spacing of 7.5m in the East and South-West directions.

5.5.5 The electrical resistivity of the soil which is a function of the resistance determined is calculated for each electrode spacing used.

5.5.6 The electrical resistivity so determined for each direction is plotted on a polar plot to obtain a closed curve. The representative earth resistivity for the test location is then determined as the radius of the circle having an area equivalent to the enclosed area within the closed curve of the polar plot.

5.5.7 The earth resistivity of the soil depends on the density, water content, grain size distribution etc. of the soil.

5.6 Field Permeability Test

5.6.1 Field Permeability Test was conducted in soil strata by Falling Head Method using open ended casing method at one location.

5.6.2 This test was carried out at 2.5m depth below the existing ground level at the specified test location.

5.7 **Percolation Test**

5.7.1 One (1) no. of Percolation test was carried out as per IS 2470-2: Code of practice for installation of septic tanks, Part II (Appendix A, Clause 5.1). The percolation test has been designated as PCT1.

5.7.2 The percolation test was conducted by excavating a pit of size 1.5m x 1.5m down to a depth of 1.5m. At the bottom of this pit, further excavation of 0.30m x 0.30m was carried out to a depth of 0.30m. All the loose material was removed from the hole and coarse sand or fine gravel was added to protect the bottom from scouring and sediment.

5.7.3 Water was then poured up to a minimum height of 300 mm over the coarse sand/gravel. In order to ensure that the soil is given ample opportunity to swell and to approach the condition it will be in during the wettest season of the year, the water wass allowed to stand for at least 24 hours. Thereafter, from a fixed reference point, the drop in water level shall be measured at every 30 minutes intervals for 4 hours.

5.7.4 The drop in the water level in the final 30mins shall be used to calculate the percolation rate. The drops during prior periods provide information for possible modification of the procedure to suit local circumstances.

5.7.5 Based on the drop in water level in the final 30 mins, the percolation rate was calculated as the time in minutes required for the water level to fall 25 mm.

6.0 LABORATORY INVESTIGATIONS

6.1 Tests on Soil and Rock Samples from Boreholes

6.1.1 The soil samples brought to the laboratory had been subjected to various tests to determine the following properties:

a) Type of soil and its gradation

b) Consistency limits

c) Natural Bulk Density & Water Content

d) Strength parameters like cohesion, angle of shearing resistance

e) Settlement Characteristics

6.1.2 In order to determine the above properties, the following tests have been conducted:

a) Sieve analysis on coarse grained soil fraction

b) Hydrometer analysis on fine grained soil fraction

c) Liquid Limit and Plastic Limit tests

d) Natural Density and Water Content determination tests

e) Triaxial Tests.

6.1.3 The rock samples brought to the laboratory are typically subjected to various tests to determine the following properties:

a) Unit weight

b) Porosity

c) Water absorption

d) Unconfined compressive strength tests

e) Point load index strength tests.

6.2 Chemical Analysis

The soil /water samples collected from the boreholes had been tested to determine the pH-value and the presence of salts harmful to reinforced cement concrete construction namely Chloride and Sulphate contents.

7.0 RESULTS & ANALYSIS

7.1 Presentation of Results

7.1.1 The results of the borehole investigations and of the laboratory investigations conducted on the soil/rock samples collected from the boreholes have been presented in the form of soil profile tables and rock profile tables.

7.1.2 The soil profile tables indicate the following :

a) Standard Penetration Test values (N-values) at various depths

b) Description identifying the type of soil and rock

c) Grain size analysis indicating composition of subsoil

d) Consistency limits

e) Natural Density and Water Content

f) Triaxial Test results.

7.1.3 The rock profile tables indicate the following :

a) Strata description identifying the type of rock strata

b) Number of core pieces of different sizes and thereupon the core recovery

c) Rock Quality Designation (RQD)

d) Rock properties like unit weight and water absorption.

e) Unconfined compressive strength

f) Point load strength.

7.2 Soil and Rock Profile

7.2.1 A perusal of the data presented in the soil and rock profile tables indicates the presence of the following four soil/rock strata at the site :

a) Stratum - I : Filled up soil intermixed with cobbles. The colour of the strata is Brownish red.

b) Stratum - II : Clayey sandy silt to Sandy clayey silt with gravel. The colour of the strata varies from Dark grey to Greyish yellow.

c) Stratum - III : Clayey silty sand to Silty sand with clay and gravel. The colour of the strata is Greenish grey with yellow.

d) Stratum - IV : Grey with white Granitic Gneiss Rock.

7.2.2 The thicknesses of the four strata in the boreholes are as follows :

Borehole No.	Strata (Depth in m : from - to)			
	Stratum-I	**Stratum-II**	**Stratum-III**	**Stratum-IV**
BH1	0.0 - 0.7	0.7 - 2.9	2.9 - 4.6	4.6 - 9.6
BH2	N.E	0.0 - 2.3	2.3 - 4.0	4.0 - 9.0
BH3	0.0 - 0.8	N.E	0.8 - 2.8	2.8 - 7.8
BH4	0.0 - 1.0	N.E	1.0 - 2.9	2.9 - 7.9

N.E : Not Encountered

7.2.3 The above results show that :

a) Stratum - I consisting of filled up soil intermixed with cobbles, had been encountered from the existing ground level and extending down to a maximum depth of 1m. Stratum - I was not encountered at the location of borehole BH2.

b) Stratum - II consisting of predominantly of silty soils, with varying percentage of sand and clay had been encountered from the existing ground level/underlying Stratum - I at the location of boreholes BH1 & BH2 only and extending down to a depth of 2.9m below the existing ground level.

c) Stratum - III consisting of predominantly sandy soils, with significant percentage of silt and low percentage of clay had been encountered underlying Stratum -I/ Stratum-II and extending down to the depths of refusal/rock strata.

d) Stratum - IV consisting of Granitic Gneiss rock, had been encountered underlying Stratum - III at depths varying between 2.3m and 4.7m below existing ground level and extending down to the maximum investigated depth of 9.6m below the existing ground level.

7.3 Soil Composition

7.3.1 The grain size distributions of the soil samples in the boreholes have been presented in the form of grain size analysis curve in figs.3a & 3b.

7.3.2 The variations in the grain size distributions of the soil in each of the strata in the boreholes are as follows:

a) Stratum - II : Clayey sandy silt to Sandy clayey silt with gravel.

BH No.	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
BH1	0	18	46	36
BH2	5 - 12	25 - 28	40 - 52	11 - 27

b) Stratum - III : Clayey silty sand to Silty sand with clay and gravel.

BH No.	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
BH1	0	48	33	19
BH2	0	49	42	9
BH3	0 - 8	44 - 55	33 - 35	10 - 15
BH4	0	49	43	8

7.3.3 The above results indicate that the soil in :

a) Stratum - II consists of about 18 - 28% of sand, 40 - 52% of silt, 11 - 36% of clay and 0 - 12% of gravel.

b) Stratum - III consists of about 44 - 55% of sand, 33 - 43% of silt, 8 - 19% of clay and 0 - 8% of gravel.

7.4 Natural Density and Water Content

7.4.1 The variations in the natural bulk densities, water contents and dry densities of the soil samples collected in the boreholes, are as follows:

BH. No.	Bulk Density (g/cm^3)	Water Content (%)	Dry Density (g/cm^3)
BH1	1.77 - 1.94	12.8 - 19.6	1.48 - 1.72
BH2	1.8	17.1	1.54
BH3	1.86 - 1.97	10.5 - 13.7	1.64 - 1.79
BH4	1.88	13.2	1.66

7.4.2 The in-situ Dry Density of the subsoil ranges between $1.48 g/cm^3$ and $1.79 g/cm^3$ and the Natural Water Content varies between 10.5% and 19.6%.

7.4.3 The above results indicate that the subsoil is in a medium stiff/medium dense to dense state down to the depths of refusal/rock strata.

7.5 Consistency Limits

7.5.1 The variations in the results of the consistency limits tests conducted on the soil samples in different strata are as follows:

a) Stratum - II : Clayey sandy silt to Sandy clayey silt with gravel.

(i) Liquid Limit : 46% to 48%

(ii) Plastic Limit : 26% to 27%

(iii) Plasticity Index : 20% to 21%.

b) Stratum - III : Clayey silty sand to Silty sand with clay and gravel.

(i) Liquid Limit : 27% to 34%

(ii) Plastic Limit : 18% to 21%

(iii) Plasticity Index : 9% to 13%

7.5.2 The above results of consistency limits indicate that the soil in:

a) Stratum-II is medium plastic in nature

b) Stratum-III is low plastic in nature

7.6 Triaxial Test Results

The angle of shearing resistance (N) of the subsoil as determined from triaxial tests, ranges between 21^0 and 29^0 and the cohesion (c) value of the subsoil varies between 0.12 kg/cm^2 and 0.26kg/cm^2.

7.7 Standard Penetration Test Values (N-values)

7.7.1 The N-values are presented in the soil profile tables. 1 to 4 and in the compiled soil/rock profile in fig.2. The N-values have also been plotted with respect to depth in fig.4.

7.7.2 Disc Filter (BH1 & BH2): The observed N-values (N:10-43) evaluated from the Standard Penetration Tests indicate that the virgin subsoil encountered at the site is observed to be in a medium dense to dense state down to the depths of refusal strata/rock strata.

7.7.3 ***Blower Building (BH3 & BH4):*** The observed N-values (N:26 -35) evaluated from the Standard Penetration Tests indicate that the virgin subsoil encountered at the site underlyingthe filledup soil is observed to be in a mediumdense to dense state down to the depths of refusal strata/rock strata.

7.7.4 In completely weathered rock, high blow counts have been recorded for small depths of penetration of the SPT sampler, indicating that the completely weathered rock encountered below refusal is very hard and compact insitu.

7.8 Chemical Analysis of Soil and Water

The results of the chemical analysis tests of soil/water samples will be provided in the Final Report.

7.9 Rock Conditions

7.9.1 An analysis of the data provided in the rock profile tables indicates the following :

a) The rock strata generally consists of Granitic Gneiss down to the maximum depth investigated.

b) The colour of the Granitic Gneiss rock is Grey with white down to the maximum depth investigated.

c) Core recoveries have been observed to be ranging from 0% to 14% at different depths in different boreholes.

d) RQD values have been observed to be nil at different depths in the boreholes.

e) Unit weight of the rock is 2.23g/cm^3.

f) Porosity of the rock is 0.86%.

g) Water absorption of the rock is 1.12%.

h) Point load strength of the rock is 389kg/cm^2.

Note : As the lengths of rock core samples recovered were not adequate, tests on Unconfined compressive strength tests could not be conducted.

7.9.2 The above analysis of the rock conditions indicates that the Granitic Gneiss rock has been observed to be generally in a Completely weathered state (recognized by nil core recovery and RQD) to occasionally in a Highly weathered state (recognised by very low core recovery and nil RQD).

7.10 Compiled Soil/Rock Profile

7.10.1 An overview of the results and their analysis has been presented in the form of a compiled soil/rock profile in fig.2.

7.10.2 The above figure shows the various strata encountered and their thicknesses in each of the boreholes and also gives the soil and rock composition and the observed N-values at different depths in different boreholes.

7.11 Earth Resistivity Test

7.11.1 The results of the Earth Resistivity Test has been analysed as given below.

7.11.2 The electrical resistivity is calculated using the following expression :

$$\rho = 2 \cdot \pi \cdot S \cdot R$$

where, D = resistivity of the soil in S-m

S = spacing of electrodes in m

R = measured resistance or megger reading in S.

7.11.3 The electrical resistivity value for each of the eight directions in which the test is conducted is determined as the mean value of electrical resistivity of successive electrode spacings in a given direction.

7.11.4 The electrical resistivities so determined for each direction are then plotted on a polar plot to obtain a polar resistivity curve. The area inside the polar resistivity curve is calculated and a circle of equivalent area is drawn. The radius of this circle gives the representative earth resistivity at the test location.

7.11.5 Polar diagram for the earth resistivity test is given in fig.5. The earth resistivity value at the test location is given below :

Earth Resistivity Test No.	Earth Resistivity (S-m)
ERT1	14

7.12 Percolation Test

7.12.1 The Percolation Rate is the time in minutes required for the water level to fall 25mm, based on the final 30 minutes of the duration of the test. The Percolation Rate as determined from the test results, is given below :

Pit No.	Depth (m)	Percolation rate (min)
PCT1	1.5m	8.3

7.13 Field Permeability Test

7.13.1 The coefficient of permeability 'k' is determined using the following expression :

$$k = \frac{\pi \cdot r}{5.5 \cdot (t_2 - t_1)} \cdot \log\left(\frac{H_1}{H_2}\right)$$

Where, r = radius of the stand pipe /Casing

H_1, H_2 = piezometric heads at times t_1 and t_2 respectively

7.13.2 The values of the coefficient of permeability 'k' so determined at the specified depth is given below :

Test No.	Depth (m)	Permeability 'k' (cm/s)
FPT1	2.5	1.51×10^{-6}

7.14 Trial Pit

7.14.1 The grain size distributions of the soil samples collected in the Trial Pit is given below:

TP No.	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
TP1	0.5	0	30	50	20
TP1	1.5	0	32	53	15

7.14.2 The in-situ natural densities and water contents of the soil samples collected from 0.8m and 1.5m depths in the Trial Pits are given in the table below :

TP No.	Depth (m)	Bulk Density (g/cm^3)	Water Content (%)	Dry Density (g/cm^3)
TP1	1.5	1.8	16.8	1.54

8.0 DESIGN CRITERIA

8.1 Design Parameters

8.1.1 The parameters required for the design of the foundation system for the proposed structures are:

a) Type of foundation to be adopted

b) Depth at which the foundations have to be laid

c) Allowable bearing pressure on the soil/rock at the foundation level.

8.1.2 On the basis of the analysis of the results of the investigations the following design parameters have been arrived at as given in the following sections.

8.2 Type of Foundation

8.2.1 The type of foundation depends upon the following :

a) Subsoil/rock conditions

b) Type of structure

c) Configuration of loading points

d) Loading intensity on each column at the foundation level.

8.2.2 The proposed structures are Disc Filter and Blower Building for the upgradation of the existing Sewage Treatment Plant project. Considering this, light loads to medium heavy loads can be anticipated on the foundations.

8.2.3 The results of the borehole investigations have shown that the top strata of subsoil encountered is loose filledup soil extending down to depths varyingbetween 0.7m and 1m below existing ground level at the locations of boreholes BH1, BH3 & BH4. Filled up soil was not encountered at the location of borehole BH2.

8.2.4 The virgin subsoil encountered at the site is observed to be in a medium dense to dense state down to the depths of refusal/rock strata encountered at depths varying between 2.8m to 4.6m below the existing ground level.

8.2.5 The results of the investigations have further shown that the rock strata in the form of Granitic Gneiss, is generally in a Completely weathered state to occasionally in a Highly weathered state down to the termination depths of the boreholes.

8.2.6 In view of the above, the foundations for the proposed *Disc Filter unit & Blower Building unit* can be supported over *Shallow Foundations - Isolated/Strip Footings, or Raft Foundations,* depending upon the requirements of the structure.

8.3 Depth of Foundation

8.3.1 The depth at which the foundations should be laid, will be governed by the following criteria:

a) Presence of filled up soil/ top loose virgin soil strata, if any.

b) There should be sufficient thickness of soil above the footings/foundations so that the bearing capacity of the soil can be fully mobilised.

c) Soil beyond the level of footings/foundations should have the requisite strength to support the anticipated bearing pressures on the foundations without allowing the settlements of the footings/foundations to exceed the acceptable limits.

d) Requirements of the type of structure.

8.3.2 The bottom level of the Disc Filter is about 3.78m asper the Section drawing provide by the client.

8.3.3 The results of the investigations have shown that the refusal/rock strata had encountered at depths varying between 2.8m and 4.6m below existing ground level in the boreholes.

8.3.4 Giving due consideration to above, the minimum depth of Foundations recommended for different structures are given below:

Structure	Borehole No.	Depth of Foundation
Disc Filter	BH1 & BH2	On Rock Strata
Blower Building	BH3 & BH4	2m below Existing Ground Level

8.4 Allowable Bearing Pressure

8.4.1 As the shallow foundations of the proposed Disc Filter are to rest on rock strata, the recommendationsfor allowablebearingpressure for foundations resting on rock strata have been made as per the provisions of clause 5.2, Table - 2 of BIS code IS : 12070 -1987.

8.4.2 For foundations resting on rock strata, the settlements will be well within the allowable settlement of 12mm in rock strata (refer BIS Code IS : 13063, page no.6, clause no. 5.2.8).

8.4.3 For foundations resting in soil strata at the location of Blower Building, the allowable bearing pressure on foundations is evaluated based on the following criteria:

a) Shear failure criterion using average soil data

b) Settlement criterion

(i) From N-values

(ii) From deformation modulus determined from triaxial tests.

8.4.4 Ground water table was encountered in all the boreholes. Hence, as a measure of abundant precaution, full submergence has been considered, while calculating safe bearing capacity based on shear failure criterion. The water table correction factor of 0.5 has been applied.

8.4.5 On account of the observed variation in level of refusal/rock strata, the thickness of the compressible soil strata below the foundations will vary, which can cause differential settlements more than allowable. Hence, for calculation of allowable bearing pressure based on settlement criterion, the allowable settlement has been restricted to 25mm for design of foundations.

8.4.6 On the basis of the above analysis, the following recommendations regarding the net allowable bearing pressure are given below:

Structure	**Depth(m) of Foundation below EGL**	**Net Allowable Bearing Pressures (t/m^2) for Widths of Foundations (m)**	
		1.5	**3 & above**
Disc Filter (BH1 & BH2)	On Rock	30	30
Blower Building (BH3 & BH4)	2	15	17
	On Rock	30	30

EGL : Existing Ground Level

9.0 RECOMMENDATIONS

9.1 Type of Foundation

Shallow Foundations - Isolated/Strip Footings, or Raft Foundations

9.2 Depth of Foundation

Structure	***Borehole No.***	***Depth of Foundation***
Disc Filter	*BH1 & BH2*	*On Rock Strata*

Structure	*Borehole No.*	*Depth of Foundation*
Blower Building	*BH3 & BH4*	*2m below Existing Ground Level*

9.3 Allowable Bearing Pressure

Structure	*Depth(m) of Foundation below EGL*	*Net Allowable Bearing Pressures (t/m^2) for Widths of Foundations (m)*	
		1.5	*3 & above*
Disc Filter (BH1 & BH2)	*On Rock*	*30*	*30*
Blower Building (BH3 & BH4)	*2*	*15*	*17*
	On Rock	*30*	*30*

EGL : Existing Ground Level

9.4 Construction Advisories

9.4.1 Loose pockets of soil, wherever encountered, should be completely removed and backfilled with well compacted earth. A 15cm thick layer of 40-50mm size gravel should be laid and rammed into the backfilled earth. A layer of sand should be placed and compacted in order to fill the voids. A leveling course of lean concrete can then be laid over the gravel, and construction of foundations can be taken up subsequently.

9.4.2 Loose pockets of weathered rock, wherever encountered, should be completely removed and backfilled with well compacted concrete. Thereafter, the leveling course of concrete can be laid, and construction of foundations can be taken up subsequently.

9.4.3 Rock Strata has been encountered at depths varying from 2.8m to 4.6m. Hence, during excavation for foundations, completely weathered rock to moderately weathered is likely to be encountered and further excavation by ordinary manual means, using crowbar and pickaxe may not be possible.This should be taken into account while planning the work.

9.4.4 For Shallow Foundations resting on rock strata, the footings should be ensured to be resting uniformly and fullyon completely weathered rock to moderately weathered rock throughout the area of the shallow foundations.

9.4.5 As the shallow foundations are to be laid close to the water table level encountered at the site, appropriate dewatering measures may have to be adopted at the site to prevent the occurrence of seepage during the excavations for layingthe foundations and to ensure that the water table level stays below the foundation levelfrom the time of layingof foundations and until the construction of the plinth beams have been completed.

9.5 Deep Excavation

The top strata of subsoil encountered at the site is loose filled up soil extending down to a maximumdepth of about 1m below existing ground level. The virgin subsoil encountered at the site is observed to be in a medium dense to dense state. Ground water table was encountered at an average depth of about 4.2m below existing ground level in the boreholes. Existing chlorination building and gravity sludge thickener units are located close to the proposed disc filter unit. Hence, adequate precautions must be taken against collapse of the sides of the excavation and foundation pits, especiallyduring rainy season.

9.6 Appendices

9.6.1 An appendix sheet showing the typical analysis of the allowable bearing pressure has been given in Appendix-A of this report.

9.6.2 A list of IS Codes referred for providing the recommendations and that which might be required to implement the same is also enclosed in this report in Appendix- B.

9.7 Note

The recommendations given in this report have been arrived at on the basis of design parameters which have been judiciously adopted by giving due consideration to the results of field and laboratory investigations as well as NAGADI's experience of over five decades in working in various types of soil and rock conditions all over India.

10.0 LIMITATIONS

This soil investigations have been carried out at selected locations in the site chosen by the clients so as to represent the entire site. The recommendations provided in this report are hence valid only for these test locations. However, if there is any change in subsoil conditions and properties at places between or beyond chosen test locations, fresh investigations will have to be carried out at such location.

Dr. N. Santosh Rao
Technical Director & Chief Consultant
for ***Nagadi Consultants Pvt. Ltd***

Appendix-A

ANALYSIS FOR ALLOWABLE BEARING PRESSURE

Location: Boreholes BH3 & BH4

Data

(i) Soil Properties :

c (kg/cm^2) = 0.13 N = 27° ((g/cm^3) = 1.90

(ii) Depth of Foundation, D (m) = 2m below existing ground level

(iii) Allowable Settlement, s (mm) = 25

Shear Failure Criterion (Ref. IS : 6403)

N_c' = 18.84 N_q' = 9.43 $N_(' = 9.50 R_w = 0.5 R_w' = 0.5

$$q_s = \frac{1}{3} \cdot \left(c \cdot N'_c + 0.5.\gamma \cdot B \cdot N_\gamma' \; Rw + \gamma \cdot D \cdot N_q' . \; R_w' \right) - \gamma \cdot D$$

B (m)	1.5	3.0
q_s (t/m^2)	14.5	16.7

Settlement Criterion (Ref. IS : 8009)

(i) From N Values

B (m)	1.5	3.0
H (m)	1	1
N_{av}	40	40
q_a (t/m^2)	23.0	19.4

(ii) From Triaxial Compression Tests : $q_a = \frac{s \cdot E}{0.7 \cdot H}$

B (m)	1.5	3.0
H (m)	1	1
E (t/m^2)	1100	1100
q_a (t/m^2)	39.3	39.3

ADOPT	**B (m)**	**1.5**	**3 & above**
	q (t/m^2)	**15**	**17**

Note : q_s and q_a are NET VALUES, Weight of backfill etc. need not be added to the loading except in case of filling above original G.L.

Appendix - B

LIST OF IS CODES

Field Investigation

1.	IS : 1892 - 2021	:	Code of practice for sub surface investigations for foundations (Second revision).
2.	IS : 2131 - 1981	:	Method of Standard Penetration Tests for soils (First revision).
3.	IS : 2132 - 1986	:	Code of practice for thin walled tube sampling of soils (Second revision).
4.	IS: 3043 -1987	:	Code of practice for Earthing (First revision)
5.	IS : 11315 - 1985 (Part 11)	:	Method for the quantitative descriptions of discontinuities in rock masses
6.	IS : 11315 - 1995 (Part 12)	:	Quantitative description of discontinuities in rock mass methods.
7.	IS: 5529 (Part1) - 1985	:	Code of practice for in-situ permeability tests.

Laboratory Tests

1.	IS : 2720 - 1983 (Part 1)	:	Methods of test for soils: Preparation of dry soil samples for various tests (Second revision).
2.	IS : 2720 - 1980 (Part 2)	:	Method of test for soils: Determination of water content (Second revision) Amendment 1.
3.	IS : 2720 - 1985 (Part 4)	:	Method of test for soils : Grain size analysis (Second revision).
4.	IS : 2720 (Part 8) -1983	:	Determination of water content - dry density relation using heavy compaction(First revision).

5.	IS : 2720 - 1985 (Part 5)	:	Method of test for soils : Determination of liquid and plastic limit (Second revision).
6.	IS 2720 - 1981 Part 12	:	Method of tests for soils : Determination of shear strength parameters using triaxial apparatus.
7.	IS 8764 - 1998	:	Method for determination of point load strength index of rocks (First Revision)
8.	IS : 13030 : 1991	:	Method of test for laboratory determination of water content, porosity, density and related properties of rock material.

Foundation Construction

1.	IS : 1080 - 1986	:	Code of practice for design and construction of shallow foundations on soils (other than raft, ring and shell) (Second revision).
2.	IS : 1904 - 1986	:	Code of practice for design and construction of foundation in soils : General requirements (Third revision).
3.	IS : 6403 - 1981	:	Code of practice for determination of bearing capacity of shallow foundations : First revision (Amendment 1).
4.	IS : 8009 - 1976 (Part 1)	:	Code of practice for calculation of settlements of foundations : Shallow foundations subject to symmetrical static vertical loads (Amendment 2).
5.	IS : 12070 - 1987	:	Code of practice for design and construction of Shallow foundations on Rocks.
6.	IS : 13063 - 1991	:	Structural Safety of Buildings on Shallow Foundations on Rocks.

SOIL PROFILE			Project : ** MLD Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru											
			B.H. Location :	Water Table : 4.4m				Term. Depth : 9.6m				B.H. No.: 1		
■ N - Value	Depth (m)	Soil Description	Grain Size Analysis					Atterberg Limits		In-situ properties		Triaxial Test		
			Gravel (%)	Sand (%)	Silt (%)	Clay (%)		Liquid (%)	Plastic (%)	Density ($_b$(g/cm^3)	Water Cont (%)	Type	c (kg/cm^2)	N (^{O})
	0.0	Existing ground level												
	0.5	Filled up soil : From 0.0m to 0.7m depth												
	0.9	Dark grey sandy clayey silt								1.77	19.6			
12	1.5	Dark grey sandy clayey silt	0	18	46	36		48	27					
	2.0	Dark grey with yellow clayey silty sand								1.85	13.5	CD	0.16	24
25	3.0	Dark grey with yellow clayey silty sand	0	48	33	19		34	31					
	3.5	Greenish grey with yellow silty sand with clay								1.94	12.8	CD	0.14	28
	4.4	Greenish grey with yellow silty sand with clay												
	4.6	Refusal strata (50 blows for 2.5cm penetration)												
		Note : 1) ■N-Value (Observed) 2) ($_b$: Bulk Density												

ROCK PROFILE

Project :** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru

B.H. Size : | Water Table (m): 4.4m | Term. Depth (m): 9.6m | B.H. No. : 1

Depth (m)	Strata Description	No. of Core Pieces of Size (cm)				Core Recovery (%)						RQD (%)	Run Time (min)	Unit Weight (g/cm^3)	Porosity (%)	Water Absorption (%)	Unconfined Compressive Strength (kg/cm^2)	Point Load Strength (kg/cm^2)	Remarks
		<10	10-25	25-75	>75	20	40	60	80	100									
4.6	-																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	25						Completely weathered rock
6.1	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	30						Completely weathered rock
7.6	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	35						Completely weathered rock
9.1	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	10						Completely weathered rock
9.6	-50/2.5cm																		

SOIL PROFILE			Project : ** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru											
			B.H. Location :	Water Table : 4.2m				Term. Depth : 9.0m				B.H. No.: 2		
				Grain Size Analysis				Atterberg Limits		In-situ properties		Triaxial Test		
■ N - Value	Depth (m)	Soil Description		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid (%)	Plastic (%)	Density (γ_b(g/cm^3)	Water Cont (%)	Type	c (kg/cm^2)	N (^{o})
	0.0	Existing ground level												
	0.5	Brown clayey sandy silt												
10	0.9	Greyish yellow clayey sandy silt with gravel		5	28	40	27	46	26					
	1.5	Greyish yellow clayey sandy silt with gravel								1.80	17.1	CD	0.26	21
21	2.5	Greyish yellow clayey sandy silt with gravel		12	25	52	11							
43	3.0	Greenish grey with yellow silty sand with clay												
	3.8	Greenish grey with yellow silty sand with clay		0	49	42	9							
	4.0	Refusal strata (50 blows for 5cm penetration)												
		Note : 1) ■N-Value (Observed) 2) (γ_b : Bulk Density												

ROCK PROFILE

Project :** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru

B.H. Size : | Water Table (m): 4.2m | Term. Depth (m): 9.0m | B.H. No. : 2

Depth (m)	Strata Description	No. of Core Pieces of Size (cm)				Core Recovery (%)						RQD (%)	Run Time (min)	Unit Weight (g/cm^3)	Porosity (%)	Water Absorption (%)	Unconfined Compressive Strength (kg/cm^2)	Point Load Strength (kg/cm^2)	Remarks
		<10	10-25	25-75	>75	20	40	60	80	100									
4.0	-																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	25						Completely weathered rock
5.5	-50/5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	30						Completely weathered rock
7.0	-50/5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	20						Completely weathered rock
8.0	-50/5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	15						Completely weathered rock
9.0	-50/5cm																		

SOIL PROFILE			Project : ** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru											
			B.H. Location :	Water Table : 4.0m				Term. Depth : 7.8m				B.H. No.: 3		
				Grain Size Analysis				Atterberg Limits		In-situ properties		Triaxial Test		
■ N - Value	Depth (m)	Soil Description		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid (%)	Plastic (%)	Density ($_b$(g/cm^3)	Water Cont (%)	Type	c (kg/cm^2)	N (^{o})
	0.0	Existing ground level												
	0.5	Filled up soil From 0.0m to 0.8m depth (Reddish brown)												
	0.9	Brownish red with yellow clayey silty sand								1.86	13.7			
26	1.5	Yellow with white clayey silty sand and gravel		8	44	33	15							
	2.5	Yellow with white and grey silty sand with clay								1.97	10.5	CD	0.12	30
	2.7	Yellow with white and grey silty sand with clay		0	55	35	10	27	18					
	2.8	Refusal strata (50 blows for 5cm penetration)												
		Note : 1) ■N-Value (Observed) 2) ($_b$: Bulk Density												

ROCK PROFILE

Project :** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru

B.H. Size : | Water Table (m): 4.0m | Term. Depth (m): 7.8m | B.H. No. : 3

Depth (m)	Strata Description	No. of Core Pieces of Size (cm)				Core Recovery (%)						RQD (%)	Run Time (min)	Unit Weight (g/cm^3)	Porosity (%)	Water Absorption (%)	Unconfined Compressive Strength (kg/cm^2)	Point Load Strength (kg/cm^2)	Remarks
		<10	10-25	25-75	>75	20	40	60	80	100									
2.8	-																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	20						Completely weathered rock
4.3	-50/5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	25						Completely weathered rock
5.8	-50/5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	20						Completely weathered rock
6.8	-50/5cm																		
	Grey with white Granitic Gneiss	5	0	0	0						14	0	30	2.23	1.12	0.94	-	389	Highly weathered rock
7.8	-																		

SOIL PROFILE			Project : ** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru											
			B.H. Location :	Water Table : 4.3m				Term. Depth : 7.9m				B.H. No.: 4		
				Grain Size Analysis				Atterberg Limits		In-situ properties		Triaxial Test		
■ N - Value	Depth (m)	Soil Description		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid (%)	Plastic (%)	Density ($_b$(g/cm^3)	Water Cont (%)	Type	c (kg/cm^2)	N (^{o})
	0.0	Existing ground level												
	0.5	Filled up soil From 0.0m to 1.0m depth (Reddish brown)												
	0.9	Filled up soil (Brownish red with yellow clayey silty sand)		0	60	29	11							
	1.5	Reddish brown clayey silty sand								1.88	13.2	CD	0.15	25
35	2.5	Yellow with grey and white silty sand with clay		0	49	43	8							
	2.8	Yellow with grey and white silty sand with clay												
	2.9	Refusal strata (50 blows for 2.5cm penetration)												
		Note : 1) ■N-Value (Observed) 2) ($_b$: Bulk Density												

ROCK PROFILE

Project :** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru

B.H. Size : | Water Table (m): 4.3m | Term. Depth (m): 7.9m | B.H. No. : 4

Depth (m)	Strata Description	No. of Core Pieces of Size (cm)				Core Recovery (%)						RQD (%)	Run Time (min)	Unit Weight (g/cm^3)	Porosity (%)	Water Absorption (%)	Unconfined Compressive Strength (kg/cm^2)	Point Load Strength (kg/cm^2)	Remarks
		<10	10-25	25-75	>75	20	40	60	80	100									
2.8	-																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	25						Completely weathered rock
4.4	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	30						Completely weathered rock
5.9	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	20						Completely weathered rock
6.9	-50/2.5cm																		
	Grey with white Granitic Gneiss	0	0	0	0	0	0	0	0	0	0	0	25						Completely weathered rock
7.9	-50/2.5cm																		

SOIL PROFILE	Project : ** Capacity Sewage Treatment Plant to ** Capacity Sewage Treatment Plant at Doddabele, Bengaluru											
	B.H. Location :	Water Table : Nil				Term. Depth : 1.5m				T.P. No.: 1		
■ N - Value	Depth (m)	Soil Description	Grain Size Analysis				Atterberg Limits		In-situ properties		Triaxial Test		
			Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid (%)	Plastic (%)	Density (γ_b g/cm^3)	Water Cont (%)	Type	c (kg/cm^2)	N (^{o})
	0.0	Existing ground level											
	0.5	Dark grey clayey sandy silt	0	30	50	20							
	1.5	Dark grey clayey sandy silt	0	32	53	15	39	22	1.80	16.8			
		Note : 1) ■N-Value (Observed) 2) γ_b : Bulk Density											

N

Schematic Site Plan

Legend

: Borehole

: Percolation Test/Trial Pit

: Field Permeability Test

: Existing Building/Structures

NOTE : Sketch Not To Scale

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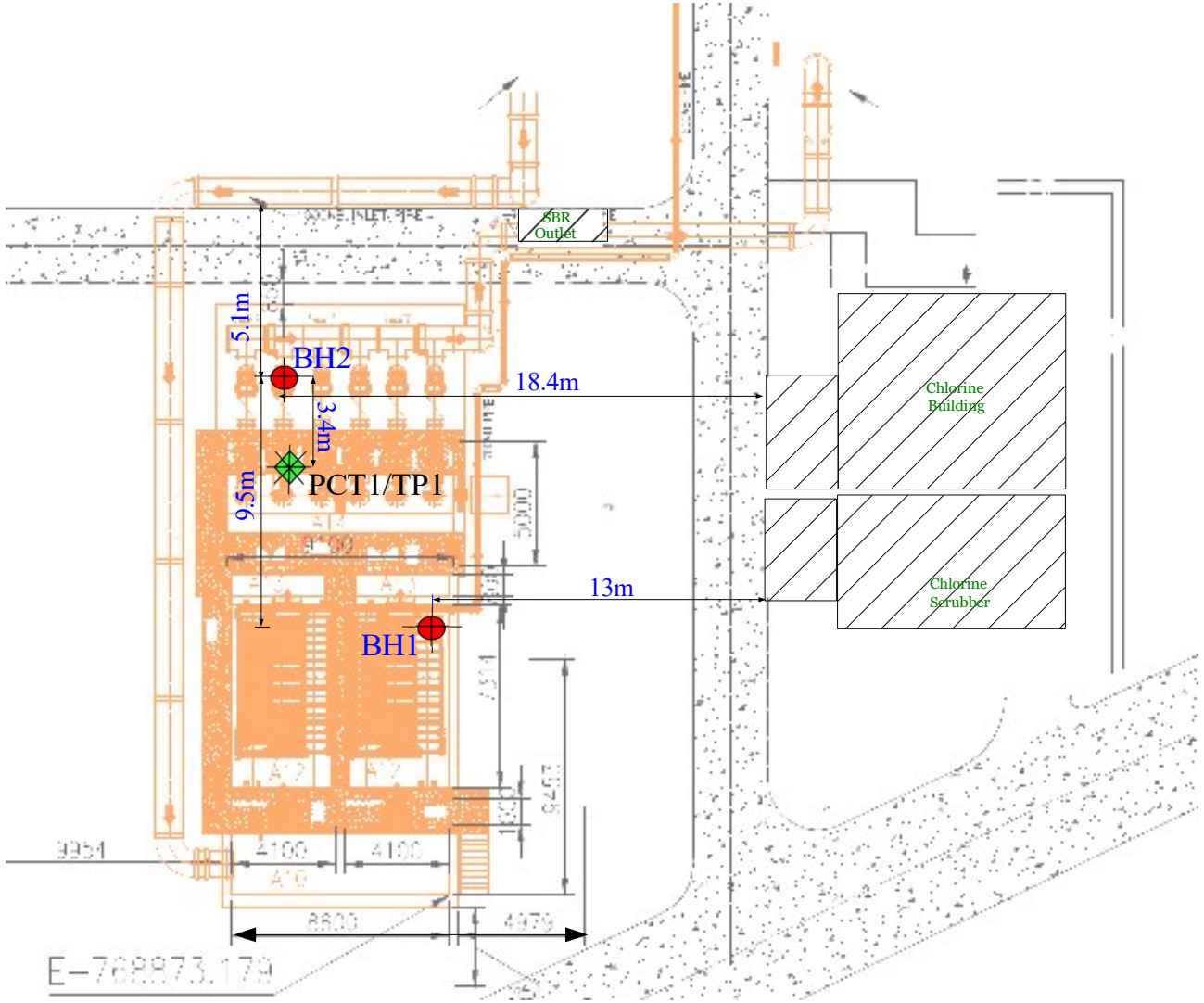
Project : Upgradation/Capacity Augmentation of Sewage Treatment Plant at Doddabele, Bengaluru.

Job No. : **G(B)13019**

Fig. No. : **1a**



Schematic Site Plan

Legend

: Borehole

: Percolation Test/Trial Pit

: Existing Building/Structures

NOTE : Sketch Not To Scale

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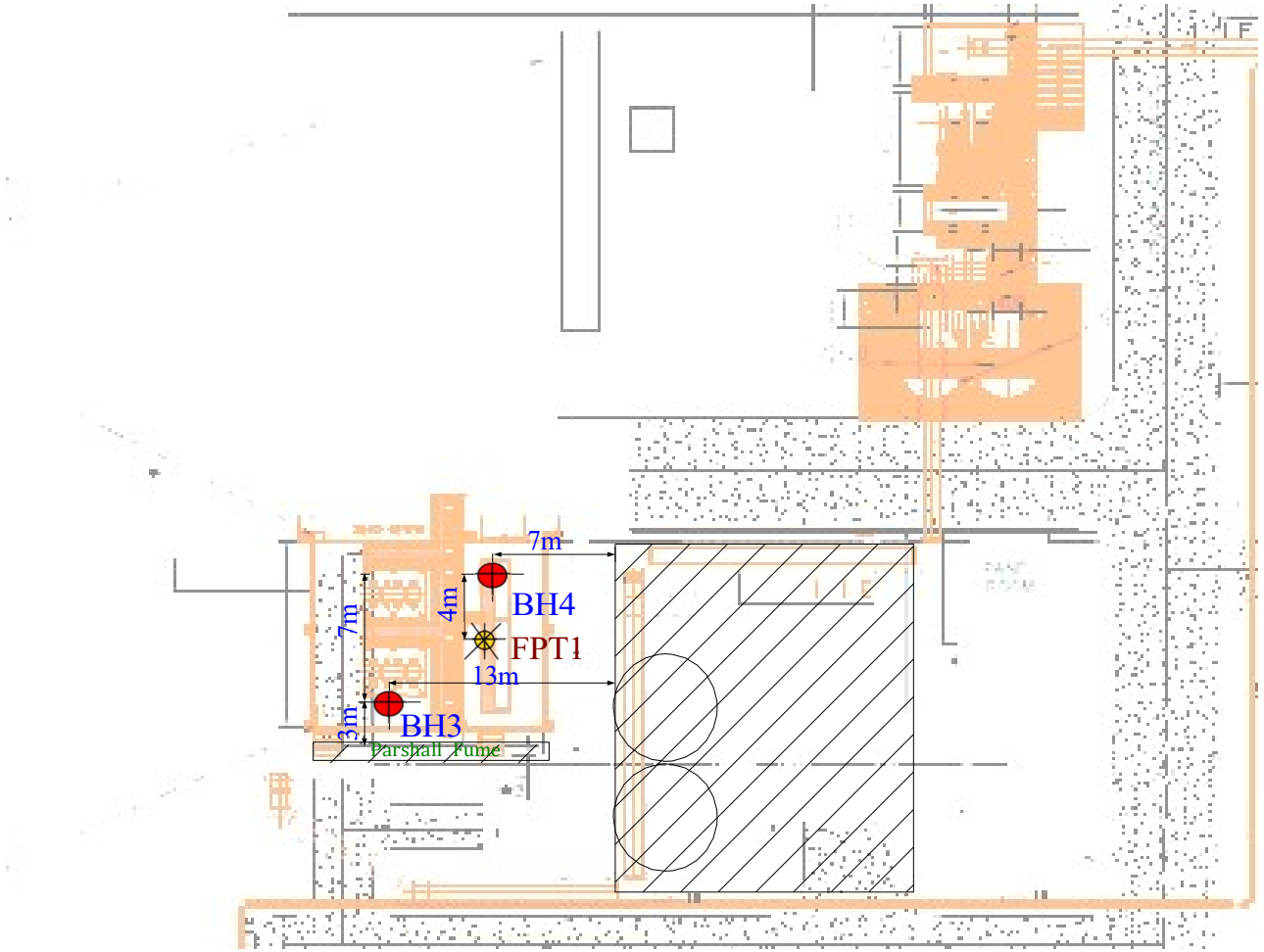
Project : Upgradation/Capacity Augmentation of Sewage Treatment Plant at Doddabele, Bengaluru.

Job No. : G(B)13019

Fig. No. : 1b

N



Schematic Site Plan

Legend

: Borehole

: Field Permeability Test

: Existing Building/Structures

NOTE : Sketch Not To Scale

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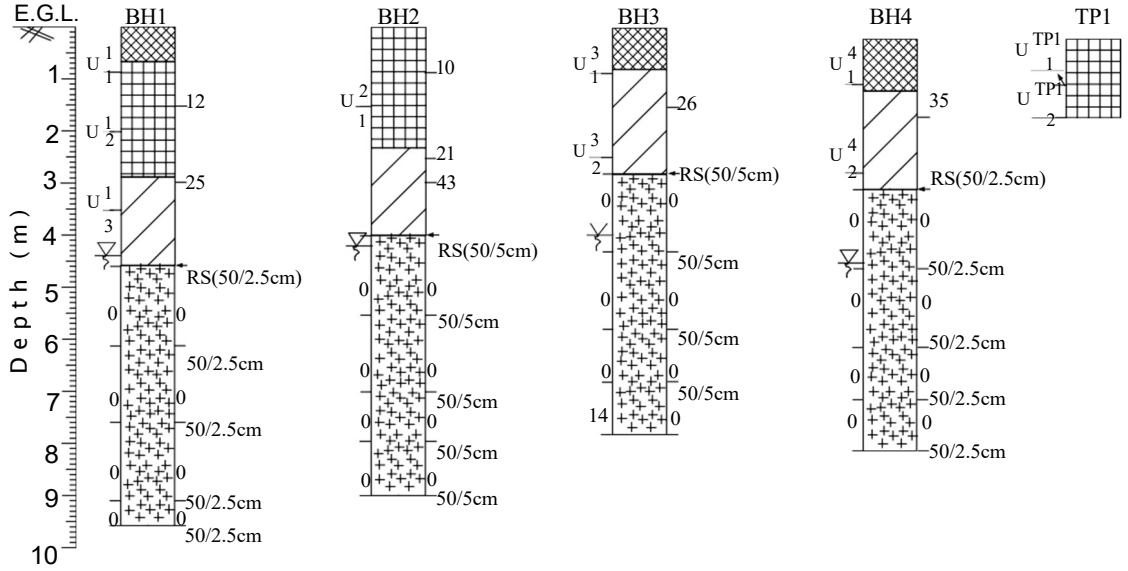
Project : Upgradation/Capacity Augmentation of Sewage Treatment Plant at Doddabele, Bengaluru.

Job No. : G(B)13019

Fig. No. : 1c



Compiled Soil / Rock Profile

Legend

Stratum - I

Filled up soil (Brownish red)
Clayey silty sand
[Gravel (0%) Sand (60%)Silt (29%) Clay (11%)]

Stratum - II

Dark grey to Greyish yellow
Clayey sandy silt to sandy clayey silt with gravel
[Gravel (5-12%) Sand (18-32%)Silt (40-53%) Clay (11-36%)]

Stratum - III

Greenish grey with yellow
Clayey silty sand to silty sand with clay with gravel
[Gravel (8%) Sand (44-55%) Silt (33-43%) Clay (8-19%)]

Stratum - IV

Grey with white granitic gneiss/
Completely weathered rock to Highly weathered rock

14 : Core recovery (%)

: RQD (%)

E.G.L. : Existing Ground Level

T.P : Trial Pit

12 : N – value (Observed)

$U\frac{1}{2}$: Second Undisturbed Sample in Borehole No.1

50/2.5cm : 50 blows for 2.5cm penetration

RS : Refusal Strata

: Water table

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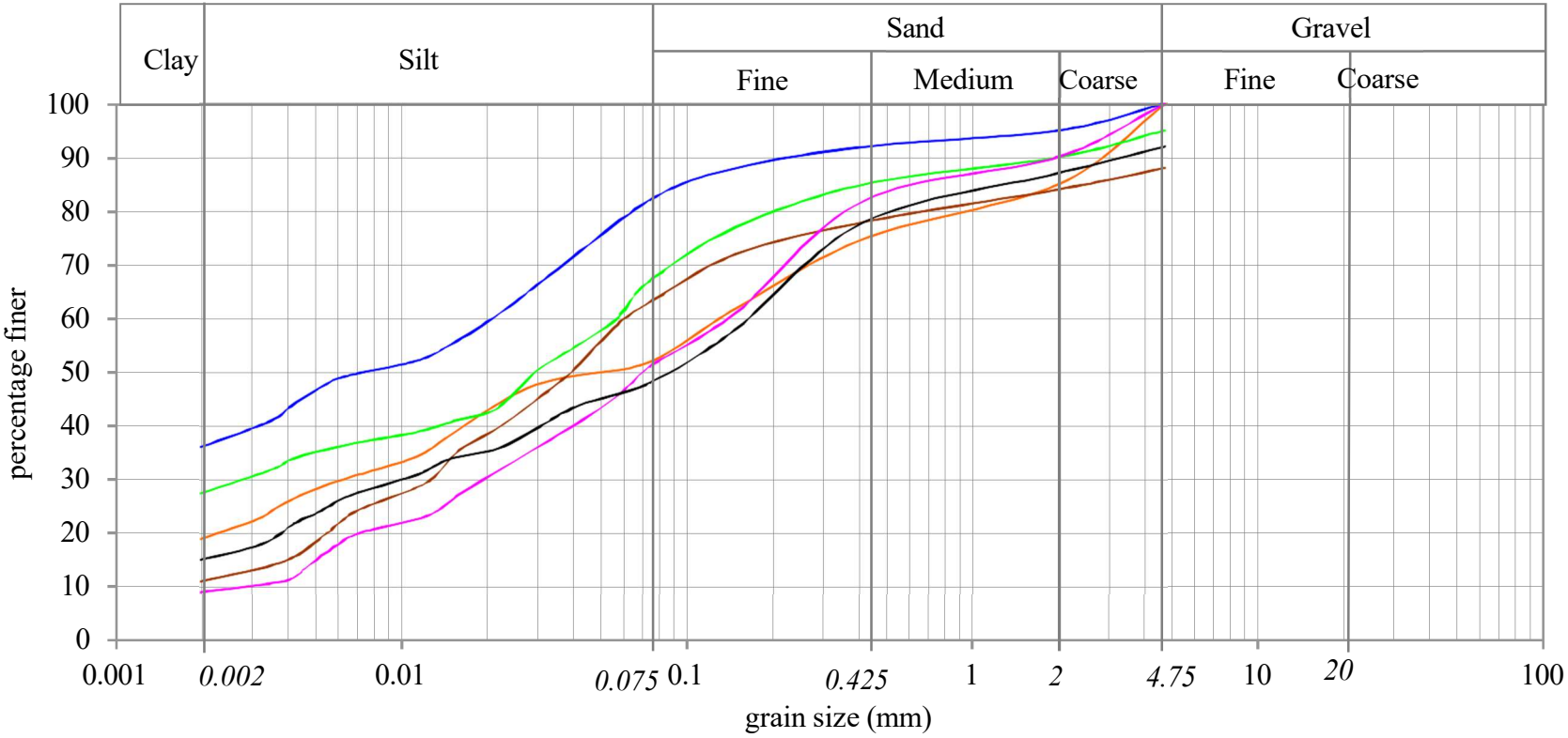
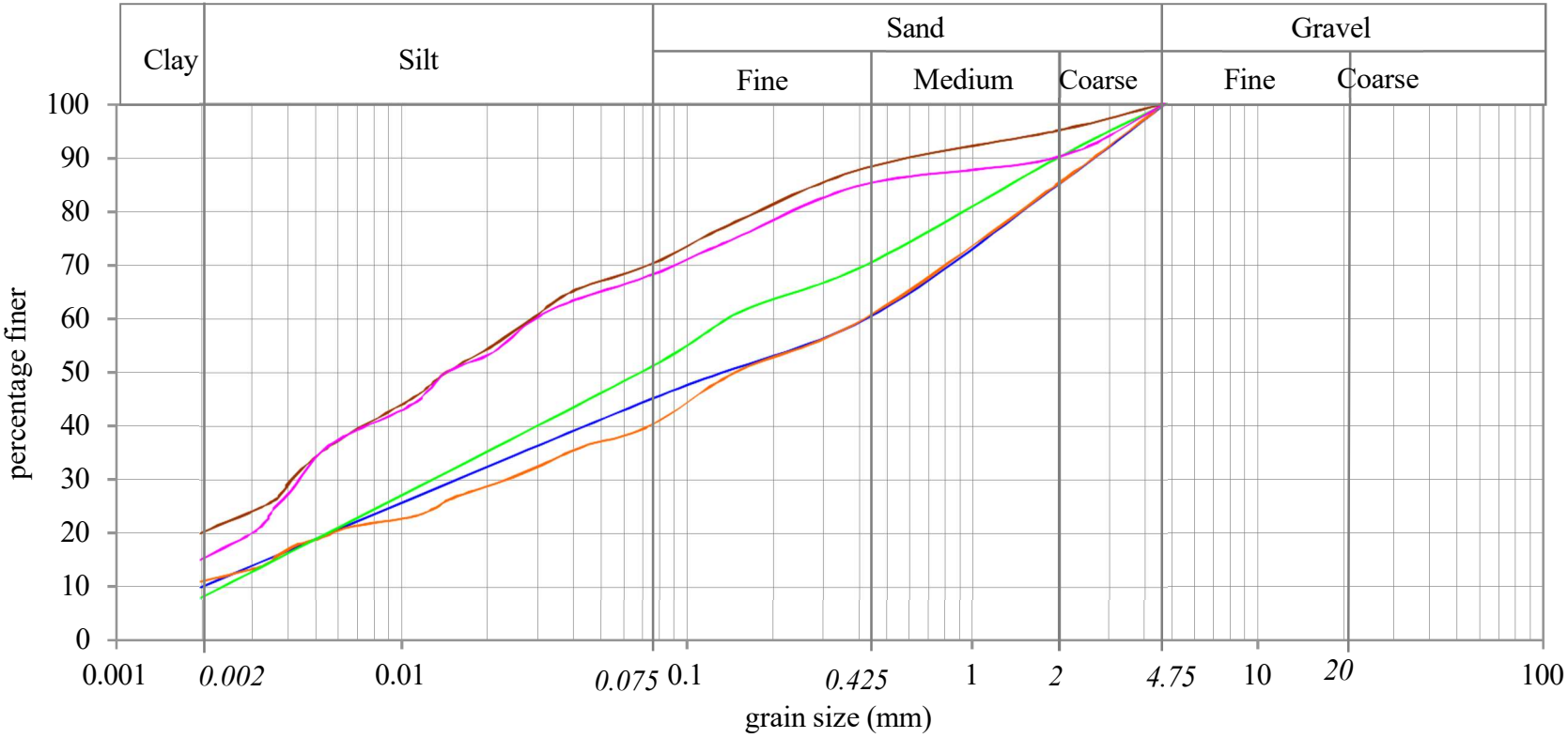
Project : Upgradation/Capacity Augmentation of Sewage Treatment Plant at Doddabele, Bengaluru.

Job No. : G(B)13019

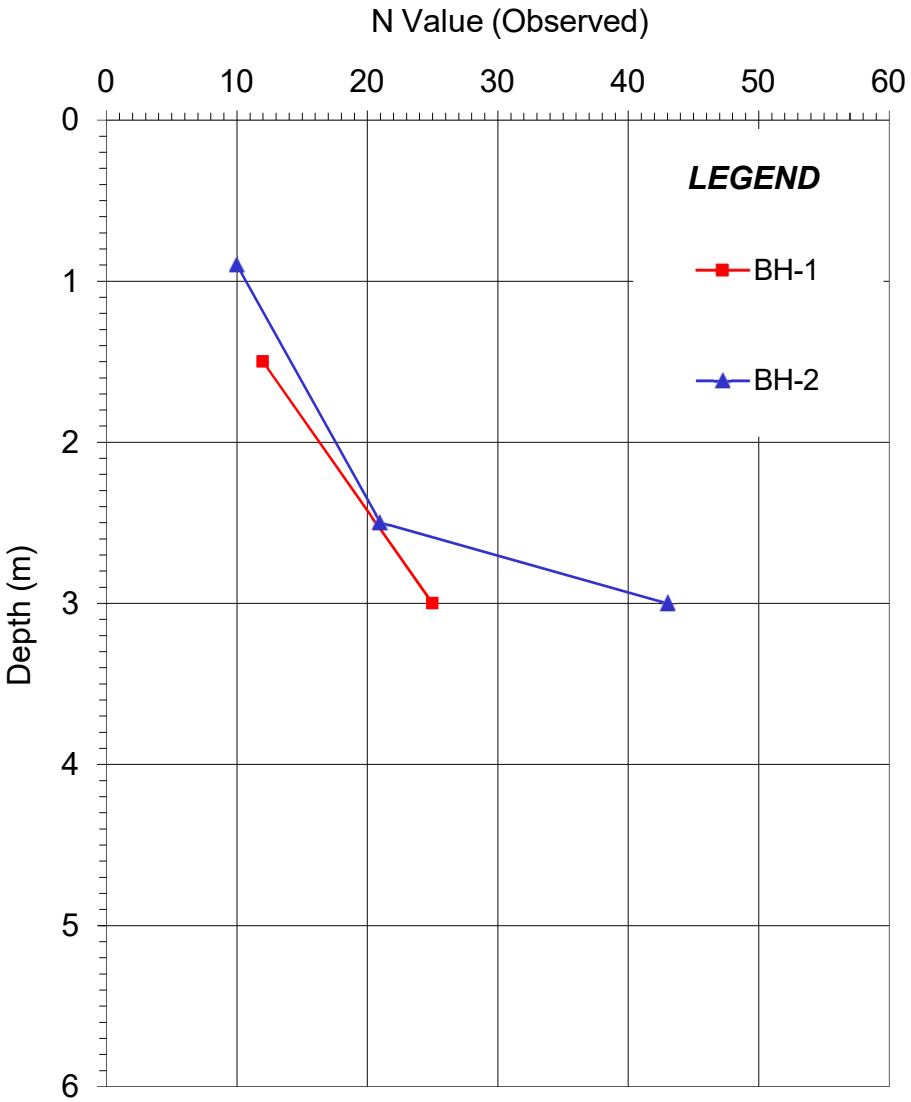
Fig. No. : 2



Line Style	Bore hole	Depth (m)	Description	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	d_{60}	d_{10}	U
	1	1.5	Dark grey sandy clayey silt	0	18	46	36	0.022	-	-
	1	3	Dark grey with yellow clayey silty sand	0	48	33	19	0.14	-	-
	2	0.9	Brownish yellow clayey sandy silt with gravel	5	28	40	27	0.065	-	-
	2	2.5	Greyish yellow clayey sandy silt with gravel	12	25	52	11	0.062	-	-
	2	3.8	Greenish grey with yellow silty sand with clay	0	49	42	9	0.15	0.0029	51.7
	3	1.5	Yellow with white clayey silty sand and gravel	8	44	33	15	0.17	-	-



Line Style	Bore hole	Depth (m)	Description	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	d_{60}	d_{10}	U
	3	2.7	Yellow with white and grey silty sand with clay	0	55	35	10	0.425	0.0021	202.4
	4	0.9	Brownish red with yellow clayey silty sand	0	60	29	11	0.425	-	-
	4	2.5	Yellow with grey and white silty sand with clay	0	49	43	8	0.15	0.0025	60.0
	TP1	0.5	Dark grey clayey sandy silt	0	30	50	20	0.028	-	-
	TP1	1.5	Dark grey clayey sandy silt	0	32	53	15	0.029	-	-



N Values vs Depth Plot

Resistivity = radius of equivalent circle = 14 Ohm-m

Polar Diagram

Earth Resistivity Test - 1